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Bulletin No. 88 - The Relation of Smelter Smoke to Utah Agriculture

John A. Widtsoe

EXPERIMENT STATION

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THE AGRICULTURAL COLLEGE

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The Relation of Smelter Smoke to Utah Agriculture.

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THE RELATION OF SMELTER SMOKE TO UTAH AGRICULTURE.

JOHN A. WIDTSOE.

INTRODUCTION.

Utah's position among the great commonwealths depends upon the degree of development of the agricultural industry of the State. As a producer of wealth, however, the mining industry exceeds agriculture. The total annual value of Utah farm products is about $17,000,000.00, while the total output from the mines is valued at $34,000,000.00. The operation of the mines, reduction mills and smelters necessitates the employment of large numbers of people, who swell the population of the State, and consume a large part of its agricultural products. Utah, which is an inland State, possessing as yet few large manufacturing enterprises, finds the markets afforded by the mining camps of decided advantage to the farmers. On the other hand, the interests of all phases of mining ventures are furthered by the proximity of prosperous agricultural communities. Agriculture and mining, the two great industries of this region, are mutually helpful, and both aid in the development and growth of the State of Utah.

Occasionally, the interests of the two industries clash. Attention has been called in earlier bulletins to cases in which the farmer and the miner must be on guard or run the risk of injuring each other.* During the last two years the attention of the Station officers has been called to the damage which the smoke from certain copper smelters, recently erected near Salt Lake City, were said to be doing to the neighboring farms. It was clear from the reports that reached us that, in many cases, the actual damage done was considerably less than the damage feared in the future; and it was equally evident that, in other cases, very serious damage had been done. The lack of correct information concerning the nature of the smelter smoke, and the effect of its constituents on soils, plants and animals, led to most extraordinary claims regarding the probable damage from the smelters

* See Bulletins 74 and 81.

and an apprehension that the agricultural district, for miles around, would have to be abandoned.

This bulletin has been prepared to throw some light on these matters, especially as to the extent, degree and nature of the damage that will in all probability result from the activity of the copper smelters in question. The conclusions are based on work done from June 6th and throughout the season of 1903. More definite results will, of course, necessitate a further study, when the seasonal conditions are different from those of 1903.

The work was done with no reference to the individual or corporation interests involved. Both the farmers and smelter people desired to know as accurately as possible the nature of the damage done by the smelter smoke; and the investigation was conducted solely with reference to the determination of the existing conditions, their cause and cure. Neither the farmers nor those connected with the smelters attempted in any way to prejudice the work; on the contrary, every opportunity was given for as full and fair an investigation as the time at the disposal of the investigator and the conditions of the season would allow.

Investigations of this kind have been carried on in Germany, England and the Eastern United States; but this is believed to be the first investigation of the kind in an arid district where irrigation agriculture is practiced.

THE DISTRICT INVESTIGATED.

The district affected by smelter smoke lies in and about the towns of Murray and Bingham Junction, some five to seven miles south of Salt Lake City. In Murray is the so-called Highland Boy Smelter, belonging to the Utah Consolidated Mining Co., a copper reduction plant, established some four years ago; about two miles south of the Highland Boy Smelter, near Bingham Junction, are two other copper smelters, the Bingham Consolidated and the United States Smelters, established respectively three and one years ago.

The Jordan river flows past these two sets of smelters, which therefore command the wide river bottoms as well as the highlands or benches on the two sides of the river. The district is one of the oldest in the State, and is thickly covered with farms and farm-houses.

The investigation here reported confined itself to the area commanded by the two sets of smelters just mentioned, and dealt especially with the lands lying between the smelters, and therefore more injured than any others. This was done because it was desired to learn the worst effects of the smelter smoke.

A. GENERAL RECONNAISSANCE OF THE DISTRICT DURING THE SEASON OF 1903.

1. The Farms Most Injured Were Studied.

From June 6th to late October, 1903, frequent visits were made to the smelter district, and the conditions of the crops grown there were carefully noted. As the first visit was made on June 6th, there are no data at hand concerning the condition of the crops in early spring.

It was strikingly noticeable that not all the farms within a given radius of the different smelters were equally injured by the smelter smoke. Some farms, lying very near the smelters, were in excellent condition, while others, some distance away, showed unmistakable evidence of injury. This was due to the prevailing directions of the winds. Farms lying in the paths of the winds suffered from the smoke, while adjoining farms, outside of the paths of the winds, showed little or no evidence of injury.

The farms which were in the paths of the prevailing winds, and which had been injured most, were studied with reference to the crop conditions upon them. The results of the following reconnaissance represent, therefore, the worst effects of the smelter smoke in the vicinity of the smelters.

2. Shade Trees.

One of the first observations made was that in certain places there was an unusually large proportion of dead or sickly shade trees. Young trees seemed to have been killed more generally than older ones. The evidence of an unhealthy condition lay chiefly in the number of yellowed or spotted leaves. which, even in early spring, gave the impression of autumn. However, these conditions of dead or sickly trees occurred only in very limited areas and were not characteristic even of the district which lay immediately around the smelters.

It was interesting to observe that the number of yellow leaves in groves of trees did not increase materially from June 6th until autumn set in. This would indicate that whatever damage was done to the trees this year was done mainly in early spring.

Careful study showed that in some cases the dead young trees had not been cared for properly, and had, therefore, suffered. Such cases formed only a small proportion of of the total injured trees. The greater part of the damage was due to something else than improper treatment.

3. Fruit Trees.

The fruit trees in several orchards were found to be in an unhealthy condition even on June 6th. The leaves of numerous

trees were strongly spotted in yellow and red. The spots frequently occurred on the under side of the leaves and could be peeled off the leaf with a small penknife. Few of the fruit trees were dead, though many had dead branches, especially among last year's growth. The spots did not seem to increase in number or size through the season; and the trees in all the orchards visited looked as well if not better in July and August than they did in June. This again would indicate that the greater damage was done in early spring.

The setting of fruit on the trees of the affected orchards was not very heavy in June. Cherries, plums and apples promised best, while pears appeared to promise least. It became quite apparent as the season progressed that leaf injury did not *always* prevent a good crop of fruit. For instance, in one orchard, a pear and a plum tree, both of which had lost most of their leaves, yielded heavy crops of fruit, while adjoining trees, with comparatively sound leaves, yielded almost nothing.

An attempt was made to determine the relative power of resistance of different trees, but with little success. It seemed that pears were most strongly affected and plums least. The other large fruits were between these extremes.

Many of the orchards investigated were poorly cared for, and could not be expected to yield very well under the most favorable conditions. It was difficult to follow the times, method and amount of irrigation of the orchards, but the continual dry condition of the soil led to the belief that the orchards in question would have been much better had they received more abundant watering.

4. Small Fruits.

In June the gooseberry and the raspberry bushes looked quite normal, and free from spots. The strawberry plants also looked as if they were in good condition; on June 18th they carried numerous ripe berries, but there were black masses of dead plants around many of the hills. Likewise, much of last year's growth on the raspberry bushes was dead, dry and brittle. The raspberries continued to look well until August 5th, when the leaves appeared slightly spotted. The gooseberry bushes continued to look well nearly the whole season, and, apparently, they yielded a fair crop of fruit. As nearly as the eye could estimate, the gooseberry bushes were the only small fruit that yielded an approximately full crop.

5. Vegetables.

Up to the 18th of June nearly all garden vegetables seemed quite normal. In one garden many turnip leaves and a few beet leaves were yellow, and the onions were slightly tipped with yel-

low. Peas, beans, cabbage, lettuce and potatoes were in prime condition. On June 21st, one of the gardens was again visited, when the beet leaves, lettuce and other vegetables had been badly burned. However, throughout the season, the garden truck continued to look fairly well, with the exception of the potatoes, the vines of which were in a bad condition from early July to the end of the season. On August 4th, small hills of medium sized potatoes constituted the potato fields. Of the ordinary garden vegetables it appeared that peas had the greatest and potatoes the least power of resistance.

The gardens in most cases semed not to be cared for in the best way, and the low yields may in part be ascribed to this cause.

6. Field Corn.

Corn did well on all the farms visited. It grew high, looked vigorous, and carried very few yellow spots on leaves or stalks. The grain was not always of the best quality, but that could hardly be ascribed to any faulty nutritive conditions surrounding the plants. On one farm a large field of corn adjoined a field of potatoes. The corn was nearest the smelter. The corn did well throughout the season, while the potatoes turned yellow late in June, and remained sickly the whole year. Corn appeared to be one of the most resistant field crops.

7. Small Grains.

Of the small grains only oats and wheat were studied; and the results were somewhat contradictory. One wheat field was in fairly good condition when first visited in June, and continued so until harvesting. Occasional yellow leaves were observed throughout this field. On another wheat field the crop, from June until harvesting, appeared to be in splendid condition.

A field of young oats was visited early in June. It was in a bad condition—almost every plant carried yellow and withered leaves. As the season progressed it grew worse, and at harvesting looked as if it was not worth the trouble of cutting.

The observations with small grains imply that the conditions to which the crop is subjected during the early periods of its life, will determine, largely, its vigor during its later life.

8. Lucern.

Lucern is one of the staple crops of the district near the smelters and a great number of fields were visited. In every case there was a fine stand of the first crop. In certain places a small proportion of leaves carried yellow spots. There was a large number of yellow leaves near the roots of the plants, but not more,

apparently, than occur in a healthy field where the crop shades the ground completely. Occasionally, red leaves were found among the yellow, which indicated some disturbing factor during the early life of the plant.

After the cutting of the first crop a number of dead roots were observed in some of the fields, though probably not more than may be observed in other fields throughout the State. This condition was not at all prevalent.

The second crop of lucern appeared normal in every respect. The yellow leaves near the roots did not seem to be more numerous than in the average lucern fields of the State.

It was practically impossible to keep a record of the irrigations of the lucern fields. Owing to the scarcity of water the third crop was not generally irrigated, hence it was not to be expected that the third crop would give a yield of any consequence.

The lucern crop seemed to be equal to the average crop of the State.

9. Pastures.

The pastures of the district lie almost wholly in the river bottom. The majority were wild pastures and apparently received little attention from their owners. The grass grew fairly well on most of them but it was dry to the touch and in appearance. The green, succulent appearance that characterizes nutritious pastures was absent. As the summer progressed they looked rather worse. In general, the pastures did not look desirable, though they possessed by no means the desolate appearance of unirrigated or overstocked pastures. It was very noticeable that the grass was frequently covered with a layer of dust (probably flue dust).

10. Flowers, etc.

Rose bushes were seriously scorched in many places, yet carried a good crop of roses. The same is true of many other flowering plants. In general, the flower gardens were in bad condition.

11. The Supply of Irrigation Water.

As already remarked, it was very difficult to get any data on the water supply and its use in the district in question. However, it appeared that most of the farmers have an insufficient water supply, especially towards the end of the season. This matter, if properly investigated, might throw some further light on the agricultural conditions of the district.

12. Actual Yield of Hay from a Lucern Field.

To arrive at some understanding relative to the actual yield of hay in the smelter district, a field was selected, and all the hay obtained from it was carefully weighed. The field selected lay freely exposed to one of the smelters. In this field a number of dead roots were observed, and it contained a number of bare spots. The farm to which this field belonged is one of the most seriously affected, and a study of this field should show the worst conditions prevailing in the the district under consideration.

The field was said to cover ten acres. The first crop was allowed to go a little too far before cutting. It was weighed soon after curing.

Total weight per field.....25,460 pounds
Yield per acre ..... 2,546 pounds

The second crop was weighed on July 21st-27th.

Total weight per field.....18,970 pounds
Yield per acre ..... 1,897 pounds

As before remarked, no irrigation was applied to the third crop; which was therefore very small, and hay was cut from only about one-half of the field.

Total weight per half field..... 2,420 pounds
Yield per acre ..... 484 pounds

The total yield for the three crops was 5,026 pounds per acre, which, with an irrigated third crop would have yielded several hundred pounds more hay.

The estimate of the size of the field, and the weighing of the hay were under the direction of the owner of the farm. No field was observed that gave promise of a smaller yield than did this one. According to the last census* the average yield of lucern per acre in Utah is 2.5 tons, with 3.6 tons in Salt Lake County.* In that case the yield from the field under discussion was about seven-tenths of the average yield.

13. The Livestock Conditions.

It was found very difficult to obtain satisfactory data relative to the condition of livestock in the smelter district, without expending an unwarranted amount of time. Horses, sheep, pigs, and poultry looked uniformly well. Among the cows on the other hand a number were in very poor condition. While on little definite information on the subject was obtained, yet it seemed that the methods of feeding and caring for live stock in this district were comparatively crude. Stables and barnyards were, in the great majority of cases, in a filthy condition. A closed dairy indicated that dairying is not a success among the farmers. Except in a few cases there seemed to be no clearly defined connection

* Vol. 6, p 218.
* Ibid. p 264.

between poor farm animals and farms in the zones of greatest injury from the smelters. The methods of feeding and treatment appeared to be important factors in the live stock conditions.

A very common complaint is that the lucern grown in the smelter district is so affected by the smelter smoke that animals fed upon the hay sicken and in many cases die. This matter was put to experimental proof. (See Section E).

14. General Condition of Crops Grown in the District.

The conclusion may be drawn from the preceding discussion that on certain farms in the vicinity in question, especially on those in the line of the prevailing winds, all kinds of vegetation were injured somewhat. The injury, however, with the majority of crops, was far from a total loss of the crop. In the case of the most injured lucern field near the smelters, the yield of hay was about two-thirds of the average yield for the district. Some of the farm animals were evidently seriously injured, but the majority seemed to be in a fair average condition.

It was also evident that the asserted injury to all farms within a given radius of the smelters had been greatly overestimated. While there can be no doubt as to the injury to the farms near the smelters and in the line of the winds, there can likewise be no doubt as to the observation that the majority of the farms in the district, not in the line of the prevailing winds, are not at all adversely affected by the smoke issuing from the smelters.

The conditions of spotted leaves and yellow plants in the line of the winds from the smelter chimneys indicated that the observed injury was due to the smelter smoke. To learn with some degree of accuracy the constituents of the smoke that injure vegetation and live stock, and the nature of their action, experiments were conducted for the purpose of determining the kinds and quantities of substances emitted by the smelters. The results of this investigation are described in the following section.

B. THE SUBSTANCES EMITTED BY THE SMELTERS.

15. The Atmosphere.

The composition of the air in the district under consideration was found to depend in general upon the direction of the wind. Judging from the smoke streaming from the smelter chimneys, it is rarely that no wind blows, for on every one of the visits made to the district during this investigation, the air currents were strong enough to carry the smelter chimneys in emphatic streams. However, the direction of the wind shifted from hour to hour and only occasionally blew in one direction for any length of time.

When the smoke from the smelters was avoided, no foreign substances were found in the air, aside from the varying quantity

of dust (not smelter dust) which in quantity depended largely upon the intensity of the wind. In the path of the smelter smoke, however, even when the air appeared to be perfectly normal to eye and nose, foreign substances could always be detected. Purposely, all the analyses and investigations were made outside of the smelters. The results obtained, therefore, represent the conditions prevailing on the farms subjected to the smelter smoke.

16. Sulphur Dioxide Emitted by the Smelters.

The most noteworthy, because the most important, substance found in the smelter smoke, was sulphur dioxide, which is the gas formed when sulphur burns. On August 25th a strong wind was blowing northward; about one-half mile from the smelters to the south, on the road crossing the river bottom, the odor of sulphur dioxide was strong and unmistakable. Analyses of the air were made at four different intervals from this crossroad to within an eighth of a mile of the smelter to the north. The amounts of sulphur dioxide found in the air were as follows:

PLACE OF SAMPLING	Percent	Parts of sulphur dioxide in 10,000 parts of air
About one-half mile north of smelters	0.00093	93
About three-fourths mile north of smelters	0.00076	76
About one mile north of smelters	0.00078	78
About one and one-fourth miles north of smlt'rs,	0.00059	59

In this case the sulphur dioxide came wholly from the southern smelters. It is also to be remarked that August 25th was unusual in that a very strong wind prevailed, which, in the river bottom, trailed quite closely to the ground.

On August 26th, the wind had shifted and was blowing from the northwest. A farm yard about one-half mile southeast from the northern smelter was so filled with the fumes of sulphur dioxide that it was difficult to breathe. Two analyses were made—one, from air in this yard and the other about one-fourth mile nearer the smelter. The results follow:

PLACE OF SAMPLING	Percent	Parts of sulphur dioxide in 10,000 parts of air
About one-half mile from smelter	0.00062	62
About one-fourth mile from smelter	0.00078	78

August 26th was also an exceptional day in that a strong trailing wind was blowing. The sulphur dioxide in this air came from the northern smelter.

Numerous other analyses were made in different places and atdifferent times, and with the wind in different directions. The

amount of sulphur dioxide varied from 93 parts in 10,000 parts of air to quantities too small to be determined with any degree of accuracy.

Tests for sulphuric acid were made in several of the air samples . Though invariably present, only traces could be found.

17. Solid Particles Emitted by the Smelters.

The amount of solid particles carried by the air which had passed over the smelter chimneys was so small that it could not be investigated by any ordinary methods of analysis. To collect large quantities of the flue dust,, special dust collectors were contrived and set up in various places near the smelters.

The collectors were all alike. Each one consisted of a large tube, made of heavy galvanized iron, six feet long, and eighteen inches in diameter, closed with a permanent bottom at one end. The other end was closed with a movable lid, like the lid of a milk bucket, with a small hole in the center. A tube led at right angles from this hole to the rim of the lid. At the extreme other end, a hole three inches in diameter was cut in the tube into which was soldered a large iron funnel with a mouth twelve inches in diameter.

To make sure of catching all solid particles, fine meshed cloth was stretched over the exit, and through which all the air entering the cans was forced to pass.

These tubes were placed in line with the smelter chimneys; the air, carrying varying amounts of solid particles, was caught by the funnel, entered the large tube where the velocity was checked, and escaped through the hole in the movable lid. During the passage of the air through the tube the solid particles were deposited. Repeated trials showed that the apparatus caught, quite completely, the solid particles carried by the air. Three pairs of these collectors were set up. The first pair (Nos. 1 and 2) was located about one-third of a mile southeast of the northern smelter and about one mile from the southern smelter. No. 1 was on the north side of a row of shade trees running east and west and pointed towards the northern smelter. No. 2 was on the south side of the trees and pointed towards the large chimney of the southern smelters. The second pair (Nos. 3 and 4) was located about midway on the line between the two smelters about 500 feet south of the road crossing the bottoms. No. 3 pointed towards the northern smelter and No. 4 towards the southern smelters. The third pair (Nos. 5 and 6) was located on the west side of the river, on a bluff about one-half mile southwest of the northern smelter. No. 5 pointed towards the northern and No. 6 towards the southern smelters.

On August 5th the collectors were placed in position; on August 26th they were opened, carefully cleaned and the material

found weighed and analyzed. The condition of the interior proved that they had not been tampered with. These results show that considerable dust is carried from the smelters, by the air; and prove that the southern smelters are as effective, in this particular, as are the northern.

Chemical examination showed these dust samples to contain a large quantity of iron, some copper and traces of arsenic. In addition were numerous particles of soil dust. That this dust really came from the smelters was proved by the large quantity of magnetic particles found in the samples. The amounts collected during 21 days were as follows:

Collector number	Facing	Weight in grams	Percent of magnetic matter	Weight of magnetic matter	Percent of copper	Weight of copper grams	Arsenic
1	North	.4500	4.6	0.0208	2.3	0.0104	Traces
2	South	.4592	9.4	0.0432	3.2	0.0147	Traces
3	North	.2800	8.1	0.0226	3.1	0.0087	Traces
4	South	.7846	16.1	0.1256	4.8	0.0377	Traces
5	North	.9932	0.9	0.0093	0.5	0.0050	Traces
6	South	.8324	2.5	0.0204	0.4	0.0033	Traces

It is noticeable that the dust which came from the southern smelters invariably contained a higher percent of magnetic matter; and the total amount was much greater.

On September 25th, thirty days after the last cleaning, the collectors were again opened. The dust was collected and weighed and analyzed as follows:

Collector number	Weight in grams	Percent of magnetic material	Percent of Copper	Weight of magnetic material	copper grams	Arsenic
1	5.91	3.0	1.6	.1773	0.0946	Traces
2	4.26	5.5	3.6	.2343	0.1534	Traces
3	1.29	2.0	4.5	.0258	0.0581	Traces
4	2.23	5.0	3.1	.1115	0.0691	Traces
5	6.95	0.5	0.7	.0348	0.0487	Traces
6	6.94	1.1	0.7	.0763	0.0486	Traces

During this period, also, dust had been carried from both smelters. That the quantity is not the same as during the first period is due, of course, to the difference in the prevailing winds during that time, or it may also be due to a difference in the activity of the smelters. It is noticeable here also that the dust from the southern smelters invariably contained a higher percent of magnetic matter; the total amount was also much greater.

While these trials with the dust collectors prove amply that the air is contaminated with foreign solid particles emitted by the smelters, yet it is gives no clue to the actual percent contained by the air. They simply show the amount that has passed through an opening 12 inches in diameter during the time specified.

The conclusion may be drawn from this study that the air in the smelter district as blown over smelter chimneys contains

variable quantities of sulphur dioxide, and solid particles containing iron, copper and traces of arsenic, and the southern smelters are as effective in this particular as in the northern smelter.

The question has been raised as to whether the flue dust particles collected by the cans were blown directly from the smelter chimneys, or were simply lifted up by the wind from the soil upon which they had been deposited and then blown into the collectors. If the latter view were correct, the results of the collectors would not prove that both sets of smelters were distributing flue dust, since one smelter might have deposited dust upon the ground which was later lifted by the wind, blowing in any direction. The fact that the percent of magnetic material was always highest in the dust from the cans pointing southward proves that the solid particles gathered by the cans came largely directly from the smelter chimneys. If the material were first deposited on the ground and then lifted by the wind, there would be no reason why the dust blown from different directions into two adjoining cans should not contain aproximately the same percent of magnetic and other matters.

C. THE EFFECT OF SMELTER SMOKE UPON SOILS.

18. The Acid Soluble Portion of the Soil.

The agricultural soils of Murray are generally more sandy than the majority of Utah soils. The sand diminishes, however, as the depth increases. Samples were taken in different places near the smelters, and two samples were digested with acid according to the official method. The first sample was taken in the river bottom, and the second on the east bench.

Sample	Depth (inches)	Percent soluble material	Percent insoluble material
1	(0-8)	9.19	90.81
1	(8-12)	11.50	88.50
1	(12-24)	11.37	88.63
1	(24-36)	15.88	84.12
2	(0-8)	12.49	87.51
2	(8-12)	12.75	87.25
2	(12-24)	14.36	85.64
2	(24-36)	29.01	70.99

19. Alkali.

After irrigation a white coating is often observed on the soil, especially on the side of irrigation furrows. Some of this material, mixed with soil, was carefully collected and the soluble matter determined. Sample No 1 was taken from the highlands, and No. 2 from the pastures in the river bottoms. The following

amounts of soluble matter were found:

No. 1 ..... 0.54 per cent.
No. 2 ..... 0.70 per cent.

The soluble matter was found to contain very small quantities of the sulphates and carbonates of sodium. This would indicate that the soils of the district are not troubled much with alkali. Certainly, alkili does not therefore decrease, materially, the yield of crops. In a few places in the river bottoms were observed small ares of land that, from the seepage from above, had accumulated large quantities of alkali, and which, therefore, were not suitable for agricultural purposes.

20. The Effect of Sulphur Dioxide on Soils.

The unfavorable effect of the sulphur gases would be to make the soils acid, and thus to retard plant growth. The agricultural soils of the district were found to be uniformly alkaline. Over 50 tests were made, but in no case did the soil give an acid reaction. There was a considerable amount of carbonates in the soil, which would naturally tend to combine with any acid substance, especially if as active as sulphuric acid, that might enter the soil. Determinations were also made of the per cent. of sulphuric acid found in the soils. The results follow:

Sample No.	Location	Per cent. of sulphuric acid
1.	Near the southern smelter.....	0.15
2.	One-half mile southeast of southern smelter.	0.19
3.	Midway between the two smelters.....	0.20
4.	One and one-half miles north of southern smelter	0.16
5.	On the west bench.....	0.16
6.	Near the southern smelter.....	0.18

These determinations show a quantity of sulphuric acid in these soils about equal to that found in average Utah soils, and certainly show no evidence of the effect of the sulphur compounds found in the smelter smoke.

This conclusion is in full harmony with numerous German and other European investigations of this subject.* It may be observed further that sulphates in a soil are not injurious to crops unless they are present in sufficient quantity to be classed as alkali. The sulphur dioxide emitted by the smelters does not injure the soils.

21. The Effect of Flue Dust on the Soils.

As shown by the analyses of the dust collected by the special apparatus described in Section 17, the only two substances contained by the dust which may injure the soil are copper and arsenic. The iron and the magnetic matter which is an oxide of copper are perfectly harmless. The dimensions of the mouths of

*Hasehoff u. Lindau, p. 46.

the collectors (12 inches in diameter), make possible an estimate of the amount of dust and dust constituents deposited over an acre. The following tables are constructed on the assumption that all the dust collected by the cylinders would have been deposited over 0.8 sq. foot of ground (6x6x3.1416), which is the area of the mouth of the funnel. This assumption unquestionably is much too high, for the collectors acted as hindrances to the free passage of the air, and collected much dust that would have been distributed over a much larger area. It is further assumed that one acre of soil to a depth of one foot weighs 3,750,000 pounds. With these assumptions it may be determined that one gram of dust collected, equals 0.003 per cent. in the first foot of soil.

If the magnetic matter and copper collected by the two collectors in each set, for the two periods of 51 days, be added, the total per cent. added to the first foot during the period, August 6th to September 25th, will be:

Collectors.	Per cent. magnetic material added in 51 days to first foot of soil.	Pounds per acre.	Per cent. copper added in 51 days to first foot of soil.	Pounds per acre.
1 and 2	0.00134	50	0.00079	30
3 and 4	0.00082	31	0.00049	18
5 and 6	0.00039	15	0.00033	12

During one year this would amount to approximately seven times the quantities of the last table.

Collectors.	Per cent. magnetic material added in one year to first foot of soil.	Per cent. copper added in one year to first foot of soil.
1 and 2	0.00938	0.00553
3 and 4	0.00574	0.00343
5 and 6	0.00273	0.00231

In ten years the increased per cents. would be as follows:

Collectors.	Increased per cent. of magnetic material in ten years. (First foot of soil.)	Increased per cent. copper in ten years. (First foot of soil.)
1 and 2	0.094	0.055
3 and 4	0.057	0.034
5 and 6	0.027	0.023

The magnetic material is not at all injurious to crops, and the amounts of copper added to the soil in ten years are not sufficient to be harmful to plant growth. Moreover, it must be remembered that the copper added to the soil is gradually worked down into the lower soil layers, thus diminishing the per cent. in the first foot. Further, the tests were made in places where the smoke effects are worst, and represent a comparatively small area of the agricultural district near the smelters. Finally, it must be recalled that these quantities, having been caught in the collectors, are much larger than those which actually settle upon the ground. It is not impossible that in some cases one-tenth of

the amounts of the above table would fairly represent the increased per cents. of magnetic material and copper.

The arsenic was very variable in the samples of dust, varying from 0.3 per cent. to traces. The amounts added to the soil are so small as to have little if any importance in the growth of crops.

From this investigation, it would appear that the effect of the flue dust upon the composition of the soils of the district is so small as to be negligible in the discussion of crop production.

To test this matter further, samples of soil were analyzed for magnetic material, which is readily and accurately obtained, and furnishes an index of flue dust contamination. The percentage found were as follows:

		Depth in Inches.		
Sample No.	0-8	8-12	12-24	24-36
1	0.240	Faint traces	None	None
2	0.020	None	None	None
	Surface soil			
3	0.036			
4	0.050			
5	0.031			
6	0.091			
7	0.072			
8	0.010			
9	0.012			
10	0.009			

These samples were all collected in places largely affected by the smelter smoke. Samples 3-10 inclusive were surface soil, which, naturally, would contain the highest percentage.

Several samples of soil were also tested for copper. In many only traces were found, which in soil selected from the most injured localities the following amounts were determined:

Number	Per cent. Copper.	Place Sampled.
1	0.009	Bench land
2	0.021	River bottoms
3	0.103	Dust collected from surface soil

Traces of arsenic were found in a number of soil samples, but the amounts were too small to be estimated.

In general, the results of the analyses of the soils agree with the calculations based upon the dust from the collectors in that the quantities of copper and arsenic and other materials added to the soil by the flue dust are so small as to be of little consequence to the farmer.

22. The Effect of the Soil upon Plant Growth.

The preceding investigation teaches that the amount of copper added to the soil by the smelters would be about 0.004 per cent. in one year, or 0.04 per cent. in ten years. The amount of arsenic

added would be one hundredth or one thousandth of the quantity of copper.

Experiments conducted in Europe have shown that the admixture of copper in an insoluble form begins to make its influence felt upon plants only when one per cent. has been added. When the copper is in a soluble form its effect is noticed when 0.01 per cent. has been added, and is very evident when 0.05 per cent. has been added. The copper from the smoke dust is largely in an insoluble condition, and it is evident that the quantities added to the soil in the district in question can have little if any effect upon plant growth.

Experiments with arsenic have shown that quantities less than 0.025 per cent have practically no effect on plant growth. The quantities of arsenic contained in the soils under discussion are largely within this limit.

Haselhoff and Lindau, whose recent book, published in 1903, contains the best known summary of the injury done to vegetation by smelter smoke, after discussing the whole subject of the effect of flue dust on the soil, conclude as follows:

"From these facts it is evident that, in general, the poisoning of soils by the flue dust particles of smelter smoke appears to be excluded; if plant injuries occur in the neighborhood of smelters, the cause of such injuries will seldom be found in the soil."

It may be concluded, safely, that the soils in the neighborhood of the smelters have not been injured by the smelter smoke.

D. THE EFFECT OF SMELTER SMOKE UPON CROP GROWTH.

23. The Direct Effect of Flue Dust on Plant Growth.

After a gentle wind the stems and leaves of crops in the line of the wind on the leeward side of the smelter were usually covered with dust, composed chiefly of flue dust from the smelter smoke. Leaves of favorable shape and in favorable positions frequently allowed the accumulation upon them of considerable quantities of flue dust. That this dust was really brought by the wind from the smelters was proved by the analyses of dust samples brushed from leaves in different localities near the smelters. The magnetic material which is characteristic and easily determined was chosen as the indicator of flue dust.

Samples	Per cent of magnetic material.
1	7.4
2	3.7
3	10.5
4	2.3
5	6.7
6	6.9
7	7.8
8	2.5

Copper was determined in samples Nos. 1 and 2.

Samples.	Per cent of copper.
1	0.58
2	0.48

Only traces of arsenic were found.

Now, it is a well established fact that any substance deposited gently and in small quantities upon plant leaves can be injurious only when it is in a soluble form. To determine the extent to which the deposits of flue dust might be injurious during a gentle rain or under the influence of dew, three direct tests were made.

1. Two leaves on a raspberry bush were found heavily covered with flue dust. In early July they were carefully sprayed with water, without washing off the dust. These leaves were watched the next day, and at intervals of about one week thereafter. No visible injury to the leaves resulted.

2. A healthy potato vine was found to be covered with flue dust. It was treated as the raspberry leaves. No injurious results followed.

3. All the leaves of a corn plant were covered with flue dust, collected from the top of a thresher. The leaves were later sprayed with water. No injury to the leaves resulted.

These tests indicate that the occasional accumulation of fine dust upon plant parts has no injurious effect upon the growth of the plants. It is also to be remembered that with the exception of a few plants, chiefly weeds, with peculiarly shaped leaves, the shifting of the wind does not allow the dust to remain very long, or in any quantity upon the leaves of the plants.

It is known that arsenic and copper, in a soluble condition, may slightly injure plant leaves, but the practical injury resulting from the deposition of dust upon plants is so small as not to be considered by students of the subject.*

It may safely be concluded that the flue dust of the smelter smoke has little, if any, part in causing the crop injuries observed in the district.

24. *The Direct Effect of Sulphur Dioxide on Plant Growth.*

If, as has been suggested in previous paragraphs, the dust in the smelter smoke exerts no important injurious action upon soils and crops, it lies near to believe that the sulphur dioxide is the chief factor in disturbing the normal agricultural conditions in the neighborhood of the smelters.

Numerous experiments have been conducted upon the influence of sulphur dioxide on the growth of plants, and it has been determined that very minute quantities, acting for long periods upon plants, are able to disturb their normal growth. Even one part of the gas in 1,000,000 parts of air, if applied continuously and long enough, has been shown to be injurious. Single or oc-

* See Haselhoff and Lindau, p. 350.

casional applications, such as characterize the intermittent blowing of smelter smoke upon any one field, have a much less injurious effect. However, a strong mixture applied for a few hours only to crops has done irreparable injury, and is perhaps most dangerous.

It is also a well established fact that in a moist atmosphere or with moistened plants the injury due to sulphur dioxide is much more severe than under dry conditions.

There can be little question that the damage done by the smelter smoke is due almost altogether to the sulphur dioxide that it contains. Observations made during the past summer bear out this view.

On June 18th a vegetable garden was carefully inspected, and found to be in good condition. On the 21st of June, the beet tops, potato vines, and many other vegetables were yellow, and withered. Inquiry elicited the fact that on the evening of the 18th and during the 19th, a stiff breeze was blowing toward this garden. The bleaching of the vegetables was undoubtedly due to the smelter smoke, and, specifically, to the sulphur dioxide it contained. Similar observations were made frequently throughout the season.

It was further observed that the injury due to smelter smoke was invariably greater immediately after an irrigation or rain than when the soil and surrounding air were dry. This is in full harmony with facts observed elsewhere.

Potatoes and other crops, the leaves of which are near the ground, seemed to be injured more than those with leaves some distance above the ground. This, in all probability, is due to the fact that the greatest amount of moisture in the air is found near the ground, and that plant parts bathed in this atmosphere are most strongly attacked. Trees are an exception to this principle.

The air in the neighborhood of the smelters, and in Utah generally, is extremely dry. From the recorded experiences of other countries, it seems that the amount of damage done by the sulphur dioxide in the smelter smoke is relatively small, owing to the dry condition of the atmosphere.

The real damage to plants occurs when a strong wind continues in one direction for a considerable length of time; and if it so happens that wet weather prevails at the same time, or that the crops have been irrigated, the damage is greatly increased.

Young plants and the young, tender parts of plants are injured more than the older plants and plant parts. This is partly proven by the observation that the relative condition of different plants throughout and to the end of the season was generally that which was observed on June 6th, when this investigation was begun. In the spring, the young, tender shoots of trees or shrubs or garden or farm crops are easily injured by the sulphur dioxide. Besides, it is then usually wet, which makes injury still more possible. In the same way the tender flowers of fruit trees and

other crops are easily injured. Undoubtedly, if the farmer knew a few days in advance when the wind with the smelter smoke would reach his place, he might so arrange the times of irrigation as to avoid any serious damage during the summer months. As it is, farming within the prevailing lines of the wind in the neighborhood of the smelters is a rather uncertain business. However, it can occur that a farm which, owing to a wet day followed by a persistent wind in the direction from the smelters, is badly injured one year, may produce full crops the next year. The experience of one year is not necessarily repeated the following year.

The leaves appear to be the only plant parts that are seriously affected. If the attacks of the smelter smoke are not too frequent it is marvelous to observe the rapidity with which the plant recuperates itself, sends out new shoots, and becomes again a normal looking individual.

The leaves are the organs of carbon assimilation. When they are destroyed, the feeding of the plant ceases wholly or in part, according to the completeness with which the leaves are destroyed. The new leaves must draw for their formation upon the stored-up materials in the tree or plant, and when they begin to assimilate carbon beyond their own needs they must first replace the material taken from the plant. In that way, little time and energy are left for the production of roots or stalks or fruit. No plant can thrive when the gathering of carbon from the air by means of the leaves is hindered or prevented. From this view, then, trees and perennlal plants would probably suffer much more than would annuals, the life histories of which extend over one season only.

Practically the whole question of injury to crop growth in the neighborhood of the smelters is narrowed down to the injury resulting from the sulphur dioxide carried by the smelter smoke.

E. THE EFFECT OF SMELTER SMOKE UPON ANIMALS.

25. *Injuries Due to Feeding Lucern Hay.*

The opinion was current in the district that lucern hay grown near the smelters contains so large a quantity of flue dust that it is unfit for use; in fact, it was asserted that numerous animals had died from eating the hay; that milch cows lose their milk flow after a few weeks' feeding on the hay, and that it is so poisonous that it cannot be used with safety in any quantity for any animals. On the farms most injured by the smelter smoke it was claimed that the lucern hay was dustier than it normally should be, and the excess of dust was said to be wholly composed of the solid particles leaving the chimneys of the smelters.

Examination showed that in some cases the hay from fields in the paths of the prevailing winds was somewhat dusty, but it was also discovered that the so-called dust consisted chiefly of crushed dead lucern leaves. If such a field has been struck by the

smelter smoke, the withered leaves are crushed and powdered in the curing, hauling and stacking of the hay, and produce the effect of dustiness.

At the same time it is evident that a certain amount of flue dust will settle upon the leaves of the lucern plants, and will be held there during the life of the crop. On the other hand, it is equally evident that the part that remains on the plants can be only a small proportion of the total amount that falls upon the soil during the same period. Still further, since the hay is handled several times during curing, hauling and stacking, the larger part of the dust must be shaken off the hay before it is finally fed to the stock.

These considerations made it seem very improbable that the stock injuries claimed were due to the poisonous nature of the lucern hay. However, since the lucern crop appears to do well in the vicinity of the smelters, and is a profitable crop covering many acres in the district, it was deemed worth while to subject the question to direct tests.

26. The Flue Dust Found in Lucern Hay.

Two bales of hay grown on the most seriously affected lucern field were carefully examined. All dust and leaves were first separated from the stalks, then the stalks violently shaken to detach any adhering particles. The collected dust and leaves were then passed through sieves of various dimensions until about two pounds of fine matter (chiefly crushed leaves) were obtained. This mass was analyzed for magnetic matter, copper and arsenic. The results follow:

	Bale No. 1, 125 pounds.	Bale No. 2, 125 pounds.
Weight of magnetic matter (grams)	0.7640	1.0317
Weight of copper (grams)	0.5358	0.5985
Weight of arsenic (grams)	0.0569	0.0513

Calculated to percentages, the following results are obtained:

	Bale No. 1,	Bale No. 2,
Per cent magnetic matter	0.00134	0.00181
Per cent copper	0.00094	0.00105
Per cent arsenic	0.00010	0.00009

The amounts contained by the hay are remarkably small. It may be objected that, in baling, a certain amount of dust was lost, and that the above results are, therefore, too low. It is to be remembered that most dust is lost at first handling, when the lucern plants lie more or less isolated on the ground. Later losses are comparatively small. Besides, should the above percentages be doubled or trebled, they would be too small for very serious notice.

27. The Poisonous Nature of the Hay Dust.

Assuming that a cow eats 25 pounds hay daily, she would consume in one year 9,125 pounds of lucern. Using the above figures, the quantities of magnetic matter, copper and arsenic consumed during the year and daily would be as follows:

	365 days.	Daily.
Magnetic matter, oz.	2.24	0.006
Copper, oz.	1.44	0.004
Arsenic, oz.	0.14	0.0004

These quantities are far below the danger limits given by standard books on the subject. If poisoning occurs from the smoke dust in the hay, it must certainly take place after very long periods of feeding, and must then be of a chronic kind. Ordinarily the amounts of copper and arsenic taken in with the hay are insufficient to cause injury to the animals.

28. The Feeding Test with Cows at Murray.

Though the above results indicate that the hay grown near the smelters is probably safe to use, yet it was thought best to test the matter further by direct experiments with milk cows. Little complaint was made about the horses of the district.

The cows were selected for this work from the herd of the Illinois Dairy, Salt Lake City. As far as known, these animals had never been in the neighborhood of the smelters, and could not have been accustomed to the conditions prevailing near the smelters.

Cow No. 1 had dropped her calf during the early part of May, 1903.

Cow No. 2 had dropped her second calf about the same time.

Cow No. 3 was about seven years old, and had calved about May 15th.

During the summer they had been on pasture the whole day, and had received ordinary bran feeds morning and night.

A quantity of hay was procured from a lucern field, which is under the influence of the smoke of the northern and southern smelters, and would probably gather more flue dust than would any other field in the neighborhood.

Another quantity of lucern hay was obtained from the field located in the Farmers' Ward, far beyond the effect of the smelter smoke.

The instructions with reference to the treatment of the cows were as follows: "Feed the three cows alike on bran and the hay from Farmers' Ward, until Tuesday, July 21st, when each of the three cows should be fed as follows:

Cow No. 1 should be fed bran and the hay from Farmers' Ward, and should receive no other feed whatever.

Cow No. 2 should be fed bran and the hay from near the

smelters, and should receive no other feed whatever.

Cow No. 3 should be pastured every day, and if fed any hay should receive only the hay from near the smelters. Cow No. 3 should also receive bran daily.

Treat the cows as nearly alike as possible. Weigh the milk obtained from each, morning and evening, and enter the weights immediately on the weekly sheets.

If any accidents or irregularities occur with the cows, please make note of it in writing, as soon as possible after the occurence."

The pasture used by cow No. 3 was under the influence of the smoke of the northern and southern smelters. Up to August 1st the cows were fed bran at the rate of 100 pounds per week for the three cows; and at the rate of 150 pounds per week thereafter.

During the ordinary period, from July 15th to 21st inclusive, the cows were fed alike. The yields of milk for this period were as follows:

Date.	Pounds of milk from Cow No. 1.	Cow No. 2.	Cow No. 3.
July 15th-21st	97	121	135

From the morning of July 22nd the cows were fed differently as outlined above. The yields of milk in the weekly periods follow:

Week.	Pounds of milk from Cow No. 1. Bran and hay from Farmers' Ward	Cow No. 2. Bran and smelter hay.	Cow No. 3. Bran, melter pasture and smelter hay.
July 22nd-28th	93	116	129
July 29th-Aug. 4th	80	113	122
Aug. 5th-11th	65	103	116
Aug. 12th-18th	75	105	114
Aug. 19-25th	80	109	121
Aug. 26th-Sept. 1st	81	120	128
Sept. 2nd-8th	88	110	127
Sept. 9th-15th	87	114	121
Sept. 16-22nd	95	119	119
Sept. 23rd-29th	93	113	113
Sept. 30th-Oct. 6th	95	115	120
Oct. 7th-13th	91	105	116
Oct. 14th-20th	85	108	119
Oct. 21st-27th	66	103	110
Oct. 28th-Nov. 3rd	61	103	117

During the first week at Murray the cows yielded somewhat more milk than at any other time. This is due undoubtedly to the better pasture, more bran and greater care which they received at the Illinois Dairy. From the moment that they arrived at Murray they received only the treatment given the stock in the neighborhood.

There is a distinct falling away in the milk yields during the two weeks August 5th to 19th. During this time the weather was very hot, the flies troublesome, and altogether it was a hard time for man or beast. That the feed was not the cause of the diminished milk yield is shown by the fact that all three cows were affected during this period. Cow No. 1 seemed to suffer most from the heat. There is a great regularity in the amounts of milk yielded by the different cows weekly; and the smelter hay did not seem to exert any adverse effect upon the total milk yield, nor did the pasture fed cow appear to suffer from the treatment given her. To make the relative variation clearer, the following table has been constructed in which the amount of milk yielded by Cow No. 1 weekly is called 100, and the yields from the other cows compared with this unit:

Week.	Pounds of milk yielded by Cow No. 1, assumed to be 100.	Corresponding No. of pounds of milk from Cow No. 2.	Corresponding No. of pounds of milk from Cow No. 3.
July 15-21	100	125	139
July 22-28	100	125	139
July 29-Aug. 4	100	141	153
Aug. 5-11	100	158	178
Aug. 12-18	100	140	152
Aug. 19-25	100	136	151
Aug. 26-Sept. 1	100	146	152
Sept. 2-8	100	125	144
Sept. 9-15	100	131	139
Sept. 16-22	100	125	125
Sept. 23-29	100	122	122
Sept. 30-Oct 6	100	121	126
Oct. 7-13	100	115	127
Oct 14-20	100	127	140
Oct. 21-27	100	156	167
Oct. 28-Nov. 3	100	169	195

In studying this table it must be recalled that every cow possesses a distinct individuality which determines the milk flow and the use which she can make of the feed presented. It would probably be impossible to find two cows that, treated alike in every particular, would give exactly the same amount of milk. The relative milk flow of two or more cows treated alike is, however, very constant, and may in a large measure be relied on to show the effect of change of feed upon milk production. For that reason the preceding table is very important.

During the first two weeks of the experiment, for every 100 pounds of milk obtained from Cow No. 1, Cow No. 2 yielded 135 pounds, and Cow No. 3, 139 pounds. After the second week the proportional amount of milk given by the cows on smelter hay and pasture was considerably higher. Cow No. 2 yielded as high as 158 pounds, and Cow No. 3, 178 pounds per every 100 pounds

from Cow No. 1. Cow No. 2 maintained a relative milk flow larger than 125 pounds per 100 pounds from No 1, until the week beginning September 23rd, when the fall was only four pounds. Cow No. 3 maintained a relative flow above 139 pounds until the week of September 16th, when the pasture was no longer in a condition suitable for use. After October 14th there was an increase in the relative flow.

The results of this table teach with considerable emphasis, that 16 weeks of feeding on lucern hay grown near the smelters, or in the pastures in the same neighborhood, does not tend to decrease the milk flow of cows below that of cows fed on lucern hay which is absolutely free from the effects of smelter smoke.

Whether evil results would follow prolonged feeding is a question that experiment only can answer; but the data already on hand show that the claims made by the farmers with respect to the effect of lucern grown near the smelters on milk cows are considerably exaggerated.

It may be objected that the cows received bran, which enabled them to keep up their flow of milk. It should be pretty well understood that to get the best results from a cow it will not do to feed her on lucern alone. Practical dairymen know this very well, and practice it. Nevertheless, if these cows had been fed on lucern and pasture alone they would in all probability have done fairly well, though the milk flow would have been smaller. The quantity of bran fed was well within that recommended by experts; yet it might have been reduced somewhat without diminishing the milk flow.*

At every milking, a tablespoonful from the milk of each cow was placed in sample bottles, and the composite samples thus obtained were analyzed for fat at intervals of about one or two weeks. The results follow:

	PERCENT OF FAT IN MILK.		
DATE	Cow No. 1	Cow No. 2	Cow No. 3
July 21-Aug. 1	3.2	3.0	3.2
Aug. 2-15	4.0	3.1	4.0
Aug. 16-31	4.0	3.7	4.6
Sept. 1-15	4.1	3.6	4.3
Sept. 16-20	4.0	3.8	4.5
Oct. 1-15	4.7	4.1	5.5
Oct. 16-31	4.4	4.2	6.0

These results do not indicate the slightest diminution of fat in the milk from Cows 2 and 3, as a result of feeding.

These cows were also weighed at stated intervals, with the following results.

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*Bulletin No. 68, Utah Experiment Station

DATE	WEIGHT IN POUNDS. Cow No. 1	Cow No. 2	Cow No. 3
July 21	700	720	1050
July 29	706	774	1023
August 4	668	777	1054
August 19	660	750	1010
September 3	740	760	990
October 1	760	820	1010
October 29	770	810	1010

The weights of the cows, as ordinarily taken on the common scales, are frequently wrong to the extent of 30 or more pounds. In addition, the condition of the cow causes a great variation. Too much importance must not therefore be attached to the weights in the above table. However, there is no indication that the cows fed on smelter hay or pasture had lost more weight than had the cow fed on hay from Farmers' Ward.

The final result from the experiments at Murray are that during a feeding period of 16 weeks, the hay grown near the smelters, and the pastures in the same neighborhood, do not exert an injurious effect upon the quantity of milk yield; in the percent of fat in the milk, or in the weight of the cows.

29. The Feeding Test With Cows at Logan.

To ascertain the feeding value of hay grown near the smelters, but fed in an atmosphere free from smelter smoke, two cows that had calved about June 15th were carefully chosen from the herds of Cache Valley, and fed at Logan.

Lucern hay in all respects similar to the smelter hay fed the cows at Murray, was baled and shipped to Logan. A quantity of first class lucern hay grown in Logan was also secured.

Cow No. 1 received the Logan hay, and Cow No. 2 the Murray hay. In addition to hay, the cows were fed about the same quantities of bran as were fed the cows at Murray.

During the preliminary two weeks, both cows were fed alike on Logan lucern and bran. The results of this period are as follows:

WEEK	POUNDS OF MILK YIELDED BY Cow No. 1—Logan hay	Cow No. 2—Smelter hay
July 19-25	337	219
July 26-Aug 1	311	209

From the morning of August 2nd the cows were fed differently as above stated. The weekly weights of milk obtained follow.

WEEK	Cow No. 1 (Logan hay	Cow No 2 (Smelter hay)	
Aug. 2-8	285	187	
Aug. 9-15	292	186	
Aug. 16-22	275	181	
Aug. 23-29	251	175	
Aug. 30-Sept. 5	266	163	
Sept. 6-12	243	155	
Sept. 13-19	235	155	
Sept. 20-26	241	159	
Sept. 27-Oct. 3	223	152	
Oct. 4-10	187	150	
Oct. 11-17	225	147	
Oct. 18-24	182	143	
Oct. 25-31	178	136	
Nov. 1-7	171	147	Placed on Logan hay
Nov. 8-14	151	140	
Nov. 15-21	150	140	
Nov. 22-28	132	139	
Nov. 29-Dec. 5	126	136	
Dec. 6-12	125	135	
Dec. 13-19	124	134	
Dec. 20-26	107	118	Placed on smelter hay again
Dec. 27-Jan. 2	100	112	
Jan. 3-9	101	116	
Jan. 10-16	96	105	
Jan. 17-23	99	109	
Jan. 24-30	100	112	
Jan. 31-Feb. 6	100	110	
Feb 7-13	93	105	
Feb. 14-20	96	107	
Feb. 21-27	92	108	
Feb. 28-Mar. 5	94	103	
Mar. 6-12	91	108	
Mar. 13-19	83	102	
Mar. 20-26	84	99	

Both the cows were taken from the pasture and placed in the barn for the purpose of the experiment. This change from pasture to dry feed in all probability accounts for the rapid drop in total milk yield during the two preliminary weeks and the first week of the real experiment. The total yield from both cows decreased considerably during the weeks of the experiment, but not in a way to be connected with the quality of the feed.

In the following table the relative yields of milk from the two cows are exhibited. Cow No. 1 is assumed to give 100 pounds

of milk each weekly period, and the corresponding amount from Cow No. 2 is calculated. The table is in all respects like the corresponding one under the discussion of the experiment at Murray.

WEEK	Pounds of milk yielded by Cow No. 1 assumed to be 100	Corresponding number of lbs of milk from Cow No. 2
July 19-25	100	65
July 26-Aug. 1	100	67
Aug. 2-8	100	66
Aug. 9-15	100	64
Aug. 16-22	100	66
Aug. 23-29	100	70
Aug. 30-Sept. 5	100	61
Sept. 6-12	100	64
Sept. 13-19	100	66
Sept. 20-26	100	66
Sept. 27-Oct. 3	100	68
Oct. 4-10	100	80
Oct. 11-17	100	65
Oct. 18-24	100	79
Oct. 25-31	100	76
Nov. 1-7	100	86
Nov. 8-14	100	93
Nov. 15-21	100	93
Nov. 22-28	100	105
Nov. 29-Dec. 5	100	108
Dec. 6-12	100	108
Dec. 13-19	100	108
Dec. 20-26	100	110
Dec. 27-Jan. 2	100	112
Jan. 3-9	100	114
Jan. 10-16	100	109
Jan. 17-23	100	110
Jan. 24-30	100	112
Jan. 31-Feb. 6	100	110
Feb. 7-13	100	113
Feb. 14-20	100	112
Feb. 21-27	100	117
Feb. 28-Mar. 5	100	109
Mar. 6-12	100	119
Mar. 13-19	100	123
Mar. 20-26	100	119

This table shows that the milk flow of Cow No. 2 was much more uniform than that of Cow No. 1, and hence the relative weights of milk increased in favor of the cow receiving smelter hay as the test progressed. There is absolutely no evidence from this test that the smelter hay has exerted the slightest unfavor-

able effect upon the milk yield of Cow No. 2. From this experiment, so far as it has progressed, nothing unfavorable can be said about the hay grown in the vicinity of the smelters. The experiment is still being continued.

Samples of milk were taken as in the case of the Muray cows, and the fat determined in them. The following results were obtained.

DATE	Percent fat in milk from Cow No. 1	Percent fat in milk from Cow No 2
July 19-25	2.9	3.8
July 26-Aug. 1	3.3	4.6
Aug. 2-8	3.3	4.3
Aug. 16-22	3.2	4.5
Sept. 6-12	3.0	4.4
Sept. 13-19	3.4	4.7
Sept. 27-Oct. 3	3.7	4.7
Oct. 4-10	3.6	4.8
Nov. 7	3.6	4.8
Dec. 1	3.4	5.0
Dec. 21	3.6	5.5
Jan. 1	3.7	5.2
Jan. 30	3.6	5.0
March 1	3.7	5.0

The percent of fat is somewhat variable but has shown no signs of diminution in the case of the cow which received the smelter hay. The tendency is rather toward an increase.

These cows have been carefuly watched but no symptoms have been noted that indicated that the cow fed smelter hay is being injured. At the present writing, after nine months feeding on the hay from the smelter neighborhood, she is in first class condition.

30. Conclusion from the Feeding Experiments.

It may be concluded from these tests that the nutritive value of lucern hay grown near the smelters is not impaired, and that the poisonous nature of the hay, if any exists, has certainly been overrated.

31. The Action of Sulphur Dioxide on Animals.

Since it is not probable that the flue dust contamination of the hay exerts a marked injurious effect upon animals, the suggeston may be made that the irritation resulting from the breathing of the sulphur dioxide of the air, results in serious injury to the air passages and lungs of animals. No experiments were made to substantiate this view, but it may be correct.

32. The Relation of the Pastures.

The pastures lying between the two groups of smelters re-

ceive a very large quantity of flue dust. Animals on pastures are of necessity required to cover considerable areas during the feeding periods, and it is probable that they gather much more flue dust than they would in the case of hay feeding. Besides, in the curing, transporting and stacking of hay, a large quantity of the adhering flue dust is shaken off. It would be a good practice for the farmers in the vicinity of the smelters to let their pastures go to hay, and barn feed their animals as much as possible.

33. A Possible Source of Poisoning.

It cannot be denied that the smelter smoke carries certain amounts of copper and arsenic that are poisonous in considerable quantities. It may be possible that in the winter much dust becomes incorporated with the snow, which, when melting, may carry with it much of the dust into some lower lying place, in which a large accumulation of dust may occur. Under the influence of air and water, a portion of the copper and arsenic may be made soluble, and when the spring and summer sun evaporates the water in the pool the water may become so concentrated that it may be very poisonous to animals that drink it. It would be expected that under such conditions the injured animals would die very suddenly. This suggestion is plausible; and farmers should examine their farms for such dangerous places, and destroy them if found.

SUMMARY OF CONCLUSIONS.

34. What the Smelter Smoke Does Do.

1. When the wind causes the smoke to beat upon a field for a considerable length of time, it tends to injure the crops severely, and thus to diminish their yields.

2. It tends to injure animals that are right in the line of the prevailing winds and therefore are compelled to breathe the smelter smoke in the air.

3. It may occasionally poison pools of standing water, when the washing of rains and melting snows cause a concentration of the flue dust in low lying places.

35. What the Smelter Smoke Does Not Do.

1. It does not injure equally all land within any given radius. The injured fields are those in the paths of the prevailing winds.

2. It does not injure the fertility of the soils of the district.

3. It does not effect materially the feeding value of crops grown in the district.

36. Some Practical Suggestions to Farmers.

1. Don't irrigate on days when wind blows the smelter smoke

towards your farm. The injuries from the smoke are always greatest when the soil is wet.

2. Animals on pasture are likely to gather more flue dust than if they are barn fed. As far as possible, therefore, grow hay on the affected pastures.

3. Trees are weakened so much by being robbed of their leaves several times in one or several seasons, that death usually follows. It is not advisable to plant orchards or trees of any kind in the districts affected by the smelter smoke.

4. Annual crops are generally the safest in smelter districts.

5. Lucern, which is a perennial, appears to withstand the effect of the smelter smoke very well, and is a safe crop for smelter districts.

6. Windbreaks of any kind, sheltering a farm from the direct action of the smoke, would do much to modify the injuries from smelter smoke.

7. Don't ascribe all your misfortunes to the smelter smoke. Be reasonable in your claims, and then insist upon your rights.

37. General Summary.

1. All the farms within a given radius of the smelters are not equally affected by smelter smoke.

2. The greatest injury occurs in the line of the prevailing winds.

3. A large proportion of shade trees, in certain districts, were badly injured.

4. The fruit trees in several orchards were badly injured.

5. The injury to the fruit trees appeared to be as great on June 6th, as at any time later in the season.

6. Pears seemed to be the least, and plums the most resistant.

7. The small fruits looked fairly well, though the last year's growth was severly injured.

8. Gooseberries, alone, among the small fruits, appeared to give a full yield.

9. Several of the small fruits showed the first effects of the smelter smoke after August 5th.

10. Garden vegetables showed few signs of injury up to June 18th; after that time some appeared quite unhealthy.

11. Potatoes seemed very sensitive to the smelter smoke.

12. Of the ordinary garden vegetables, peas appeared to have the greatest, and potatoes the least power of resistance.

13. Field corn seemed to be very resistant.

14. Small grains do well, if not injured when young.

15. The lucern fields, with very few exceptions, looked equal to the Utah average.

16. The pastures lie in the river bottoms between the two sets of smelters, and therefore receive much smoke.

17. The pastures did not look first class, yet were not bad.

18. The flower gardens were generally in a poor condition.

19. The actual yield of lucern hay from one of the worst fields in the smelter district was nearly 6,000 pounds per acre.

20. The poorest lucern fields in the neighborhood of the smelters yield not less than two-thirds of a normal crop.

21. The condition of live stock was quite good. In a few cases there were evidences of injury from the smelter smoke.

22. In general, the injury done to crops by the smelter smoke is far from a total loss of the crop, and only the farms lying in the paths of the prevailing winds are suffering seriously.

23. On the windward side of the smelters the air contains no foreign substances.

24. On the leeward side the air was found to contain from 93 parts of sulphur dioxide in 10,000 parts of air, to quantities too small for accurate determination.

25. Only traces of sulphuric acid were found in the air.

26. The air passing over the smelter chimneys contains considerable quantities of flue dust, containing small amounts of copper and arsenic.

27. The sulphur dioxide and sulphuric acid from the smelter smoke have not injured the agricultural value of the soils near the smelters.

28. The flue dust deposited by the smelter smoke does not affect the soils unfavorably.

29. The flue dust in the soil is not sufficient to affect plant growth.

30. The accumulation of flue dust upon the leaves and other parts of plants does not affect plant growth unfavorably.

31. Very minute quantities of sulphur dioxide will injure plants.

32. The greater part of the damage done by smelter smoke is due to the action of sulphur dioxide.

33. Injury from this gas occurs most readily with young, juicy plants, or in wet weather, hence, the spring season, and times of irrigation are the most dangerous periods.

34. Permanent injury seldom resluts from one application of sulphur dioxide.

35. The dust found in the lucern hay is due, largely, to the crumbled leaves that have been killed by the smoke.

36. The amount of flue dust found in lucern hay is so small as to have little, if any, effect upon animals eating the hay.

37. Cows fed for twelve weeks and for nine months on smelter hay were not at all injuriously affected.

38. The sulphur dioxide of the air may injure animals.

39. Cattle on pasture take into their systems more flue dust than do barn-fed animals.

40. When the snow melts, the flue dust may be concentrated in some pool and thus poison animals that may drink of the water.